NONDESTRUCTIVE EVALUATION OF BIOLOGICALLY DEGRADED WOOD

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INTRODUCTION

Wood is a complex material that can be attacked and degraded by a wide range of biological organisms. The USDA Forest Service, Forest Products Laboratory (FPL), has been investigating the use of nondestructive evaluation (NDE) techniques to identify when degradation of wood occurs in the structure and the performance characteristics that remain in the structure. In particular, FPL's work has focused on using longitudinal stress wave NDE techniques for laboratory and field applications.

Techniques of NDE are increasingly being used in industrial applications to assess various properties of wood and wood products and in-place wooden structures. One NDE technique that is commonly used to evaluate mechanical properties of wood products is based on the measurement of vibrational characteristics. Longitudinal stress wave NDE techniques use low-level stress waves to measure two fundamental energy properties: storage and dissipation. Energy storage is the speed at which a wave travels in a material. Energy dissipation is the rate at which a wave attenuates. These properties are related to the same mechanisms that control the mechanical behavior of a material. Consequently, useful relationships can be obtained between stress wave speed and attenuation and the elasticity and strength of a material.

Ross and Pellerin (1988) found that stress wave speed and attenuation are excellent indices of the mechanical properties of wood-based composites. Under controlled laboratory conditions, Pellerin and others (1985) showed that stress wave velocity is a good indicator of wood decomposition when caused by brown-rot fungi but a poor indicator when caused by termites.

We believe that NDE techniques incorporating both stress wave speed and attenuation may yield useful information about the residual strength of solid wood subjected to naturally-occurring biological attack, independent of the type of attacking organism. Therefore, a project was undertaken to assess the feasibility of using stress wave NDE techniques in the field to estimate the mechanical properties of wood that are subjected to various stages of degradation as a result of biological attack. The first part of the project was devoted to developing a simple and inexpensive technique that could be used to observe stress wave behavior in small wood specimens. Because of the difficulties of the

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measurement systems and excitation methods, prior stress wave research of this type has been restricted to large wood specimens. This paper describes the NDE technique that we developed and some typical results obtained from the technique, using both sound and degraded wood.

EXPERIMENTAL SETUP

A illustration of our experimental setup is shown in Figure la. All specimens were Southern Pine sapwood. A Kynar[2] piezofilm vibration sensor (Model SDT1-028K) was attached to the top surface of a specimen using double-sided adhesive tape. A stress wave

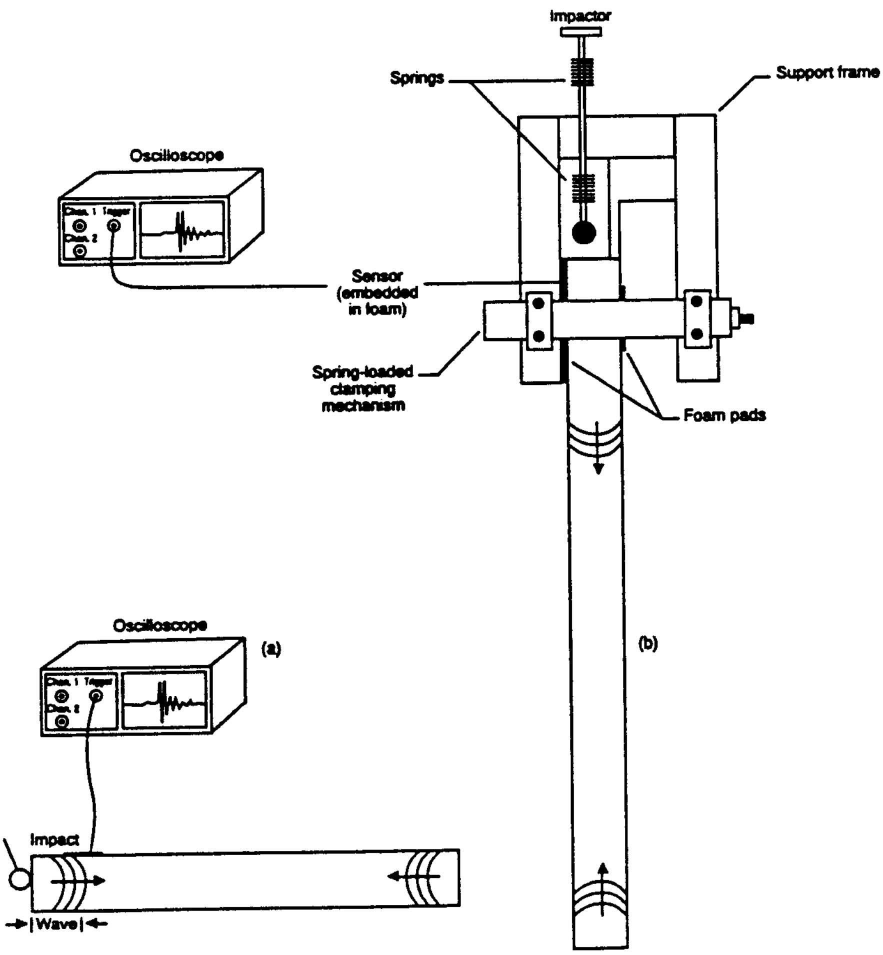

Figure 1. Experimental setup: (a) initial, (b) modified.

[2]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

was induced through a small pendulum impactor. The impactor consisted of a 0.125-in-diameter (0.003-m) steel ball suspended by cotton thread from a small wooden frame. In response to a wave traveling in the specimen, output of the sensor was monitored and recorded using a Nicolet Model 2090 III digital storage oscilloscope.

Experience with this experimental setup provided us with the following notations. Coupling of the piezofilm to the specimen was a key element in obtaining a good signal response. A consistent method of coupling would have to be designed to facilitate a large number of specimens in an experiment. A lengthy lead wire with a properly shielded connector would be necessary to ensure low-level noise signal responses. Covering the film with regular cellophane tape would protect the metallic surface so that it would not be destroyed after numerous tapings. The heal of the film detector would also have to be taped securely to obtain a consistent signal. The Nicolet Model 2090 III and the larger Model 4094 have limited capabilities to store data files--8 records and 20 records, respectively. In addition, these computers have limited capabilities for field-type testing because of their large size. The impact system was also a source of inconsistency. A pendulum with a rigid shaft and various-sized steel balls would need to replace the original string and ball impactor. A pinball-type impactor could also be used. A consistent signal would be achieved by varying the size of ball and the strength of the springs.

All previous notations were considered in modifying the experimental setup for sampling infield and laboratory bench specimens (Fig. lb). A hand-held pinball impactor with imbedded piezofilm sensor was designed, which had the ability to be easily and quickly attached to the specimen with a single snap-on motion. A piece of 100-grit sandpaper was taped to the imbedded sensor. This gave good coupling to the specimen, resulting in consistent signal output. A portable Nicolet 310 digital storage oscilloscope was used to monitor and store the waveforms. This scope was easy to carry in the field and stored 88 waveforms on a 3.5-in. (0.089-m) floppy disk. This scope uses IBM PC compatible data disks that can be copied for backup. These modifications to the experimental setup provided us with easy data acquisition, data storage, and subsequent waveform analysis.

WAVEFORM ANALYSES

In using our experimental setup, elementary wave theory (Kolsky 1963) suggests that the waveforms should consist of a series of equally spaced sine-shaped pulses whose magnitude decreases exponentially with time (Fig. 2). The speed C at which a wave moves through a specimen can be determined by coupling measurements of the time between pulses, peak to peak Δt, and the length L of the specimen using the following equation:

$$C = \frac{2L}{\Delta t} \tag{1}$$

Wave attenuation can be measured as the rate of decay or logarithmic decrement δ of the amplitude of pulses using the following:

$$\delta = \frac{1}{j} \ln \frac{A_o}{A_j} \tag{2}$$

where A_o and A_j are the amplitudes of two pulses j cycles apart

This analysis method is an estimate that can be improved by using additional pulses to give an average result. Using the time value between several pulses and dividing by the number of cycles gives an accurate C value. In addition, using a high value of j in Equation (2) gives an accurate value.

If the values of the peak amplitudes are collected, a curve can be fit to the set, giving an equation of the form:

$$f(t) = Ae^{-nt} \tag{3}$$

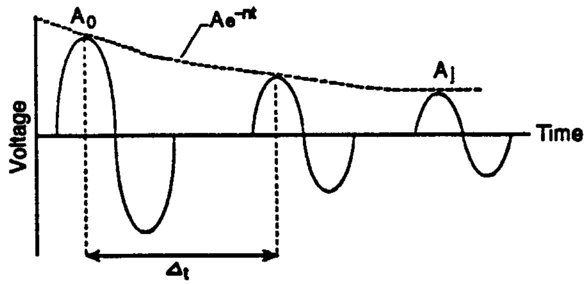

Figure 2. Elementary wave response theory, Eq. (2), (3).

This equation describes the outer envelope of the original pulse signal and is a decreasing exponential function. By taking the natural log of both sides of the equation, a linear equation results, where *n* is slope of the line.

$$\ln f(t) = \ln A - nt \tag{4}$$

By using the peak values of the waveform, a linear relationship can be generated. The slope of the line will determine the constant *n*. The slope *n* of this line is directly proportional to δ.

$$\delta = n\,\Delta t \tag{5}$$

Compared to the previously described waveform analyses, this gives the most accurate results. A computer was used to find the peak values and evaluate the necessary parameters from each waveform captured on disk. Using Lotus 123, a worksheet was used with an appropriate macro to find the peaks, linearize the values, calculate the parameters, and list the results in a separate spreadsheet Experiments with large sample volumes were analyzed quickly and results compared for changes that may occur between sample volume sets.

Computer data acquisition and analyses. with instant feedback of results, would greatly assist infield testing. Software using this technique has been written and is presently being tested at the FPL. Small computers with appropriate hardware capabilities will eventually be available and used for field applications.

RESULTS

An oscilloscope trace of a waveform obtained from monitoring stress wave behavior, in the laboratory with free boundary conditions, on a typical 1- by 1.5- by 40-in. (0.025- by 0.038 by 1.016-m) control specimen is shown in Figure 3. Note that the waveform consists of a series of equally spaced sine-shaped pulses whose magnitude decreases with time, as predicted by elementary wave theory (Kolsky 1963). Also note that the small impactor generated waves of sufficient magnitude so as to yield an observable response. In addition, the short duration of the impact generated a wave that yielded pulses with significant separation between them. Separation is necessary for accurate measurement of the velocity at which a wave travels in a specimen. If the length of a wave is excessive, the wave overlays on itself, causing inaccurate velocity measurements.

An oscilloscope trace of a waveform taken in the laboratory from specimens that were in the field 6 months and exposed to natural decay and other biodegradation is shown in Figure 4. The following value differences were recorded between the control and degraded specimens in waveform parameters:

	Control	Degraded
Time between pulses (Δt)	0.000391 s	0.000473 s
Slope of line (n)	278	665

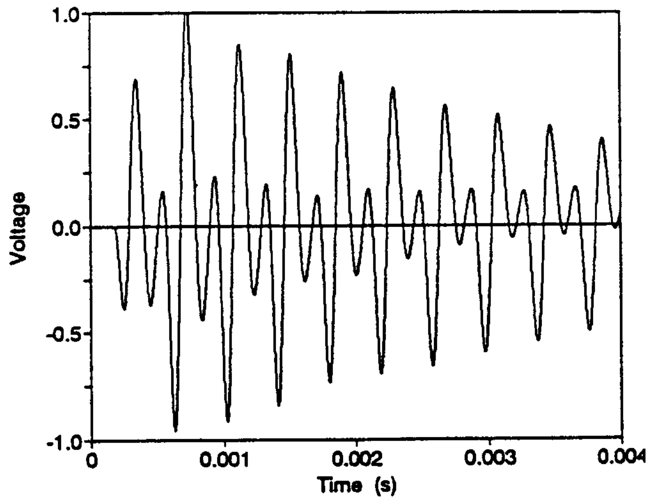

Figure 3. Typical control specimen waveform.

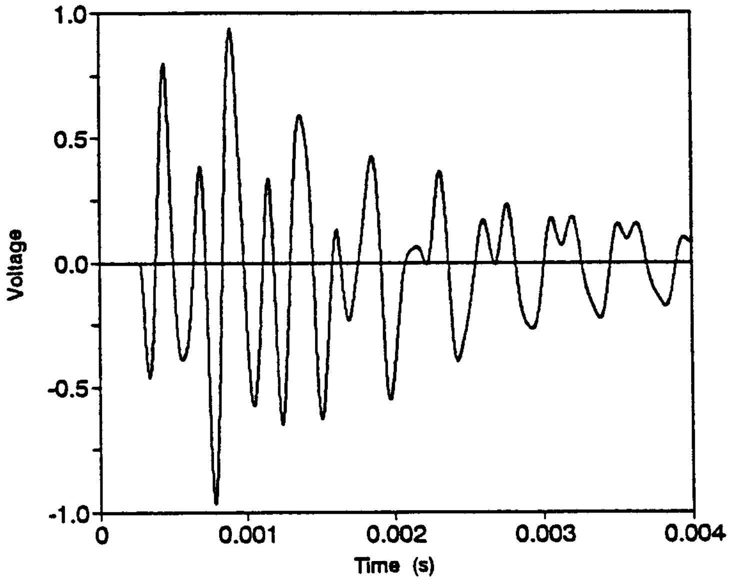

Figure 4. Typical degraded specimen waveform.

Note that the slowest wave (larger Δt) and rate of attenuation of the peak amplitudes were greater (larger *n*) for the degraded specimen than for the control.

We feel that these differences can ultimately be used to determine residual strength in naturally decayed and degraded wood members. We are building a database to show the relationship between wave parameters and residual strength of biologically degraded wood. Several types of degradation agents, which represent a common range, are being utilized to degrade wood. Our research should ultimately have application in field evaluations of candidate preservatives and in engineering assessment of residual strength in existing structures.

CONCLUDING REMARKS

The first step in using an NDE technique for monitoring biological degradation of wood members is developing an inexpensive, readily available measurement system. The measurement system for monitoring stress wave behavior in degraded wood consists of an impact and signal acquisition system coupled to a relatively inexpensive data storage device. Signal analysis is also performed using inexpensive personal computers. Results are easily analyzed and compared to give the researcher near real-time information.

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